

## **Tropical Cyclone Wave and Intensity Forecasts**

Charles R. Sampson  
Naval Research Laboratory  
7 Grace Hopper Ave  
Monterey CA 93943-5502  
phone: (831) 656-4714 fax: (831) 656-4769 e-mail: [sampson@nrlmry.navy.mil](mailto:sampson@nrlmry.navy.mil)

Document Number: N0001409WX20179  
[http://www.nrlmry.navy.mil/atcf\\_web/wavewatch](http://www.nrlmry.navy.mil/atcf_web/wavewatch)

### **LONG-TERM GOALS**

The goal of this project is to improve guidance for the prediction of waves and intensity associated with tropical cyclones.

### **OBJECTIVES**

The objectives of this project are to develop, test and evaluate new strategies to predict (a) tropical cyclone generated waves and (b) tropical cyclone intensity as measured by one-minute mean maximum sustained wind speed.

### **APPROACH**

Develop a method to forecast waves that are consistent with tropical cyclone warnings/advisories from the Joint Typhoon Warning Center (JTWC) and the National Hurricane Center (NHC). This involves obtaining the current forecast from the operational centers, and generating a tropical cyclone surface wind circulation for each forecast time in the forecast. These analyses are then inserted into a background NWP model surface wind field and used as input to WAVEWATCH III (Tolman et al. 2002). Existing tropical cyclone circulations in the NWP model forecast fields also should be removed prior to inserting the vortex generated from the operational center forecast. Results will be evaluated against available buoys or other observations. The wave forecast algorithm must be designed to operate within the constraints of the Fleet Numerical Meteorology and Oceanography Center (FNMOC) infrastructure and must be efficient in that the products can be made available to users within six hours of the warning/advisory dissemination. Paul Wittmann (FNMOC) and Hendrik Tolman (National Centers for Environmental Prediction) will serve as technical consultants on WAVEWATCH III and assist in evaluation of results.

Improve intensity forecasts from the Statistical Typhoon Intensity Prediction System (STIPS) and other forecast models. This task involves experimenting with new formulations of STIPS and designing multi-model ensemble aids that include promising results from the STIPS and other techniques. The results of the experiments will be published and improvements to multi-model ensemble aids will be transitioned to operations through the Automated Tropical Cyclone Forecast System (ATCF; Sampson

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>2009</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2009 to 00-00-2009</b>	
4. TITLE AND SUBTITLE <b>Tropical Cyclone Wave and Intensity Forecasts</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Research Laboratory, 7 Grace Hopper Ave, Monterey, CA, 93943</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <b>The goal of this project is to improve guidance for the prediction of waves and intensity associated with tropical cyclones.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

and Schrader 2000). John Knaff and Mark DeMaria (NOAA) will provide technical expertise on STIPS, James Franklin (NOAA) will provide expertise on NHC operations, and Gustavo Goni (NOAA) will provide an ocean heat content product for STIPS development.

## **WORK COMPLETED**

### *1. Wave forecast algorithm*

In collaboration with Paul Wittmann (FNMOC) and Hendrik Tolman (National Centers for Environmental Prediction), we completed the prototype version of WAVEWATCH III (Tolman et al. 2002), which uses tropical cyclone warnings from the Joint Typhoon Warning Center (JTWC) as input (hereafter named JTWC/WW3). The emphasis was on developing an algorithm to generate a realistic cyclonic vortex and merge it with background fields provided by a numerical weather prediction (NWP) model with its vortex removed. The JTWC/WW3 algorithm has been executed in real-time for the entire 2008 and 2009 seasons and has been used on occasion by various Navy and National Weather Service forecasters. The Naval Maritime Forecast Center (NMFC) has performed a short evaluation with the conclusion that JTWC/WW3 should be transitioned to operations at FNMOC. A manuscript describing this technique has been written and is being submitted for publication.

### *2. Intensity forecast algorithm*

In FY09, we evaluated two upgraded intensity consensus aids (originally explored and published within this project (Sampson et al. 2008) that are now used in operations at NHC. An application of ocean heat content fields to intensity forecast guidance has been evaluated and published. Finally, three intensity aids developed for the Southern Hemisphere have been documented and published.

## **RESULTS**

### *1. Wave forecast algorithm*

Funding of this project resulted from issues related to a sortie from Yokosuka, Japan during 2006, which in hindsight was determined to be unnecessary since the forecasted 12-ft seas never arrived on the coast near Tokyo. Figure 1a shows a 72-h NOGAPS<sup>1</sup>-driven WAVEWATCH III (NOGAPS/WW3) forecast from September 19, 2006 at 12 UTC available with the JTWC forecast from September 19 at 18 UTC. This chart was used in the Yokosuka sortie decision. The 12-ft seas encroached on Tokyo Bay by the 84-h forecast and ships were sortied to give them time to steam far enough southwest to avoid the approaching high seas associated with Typhoon Yagi.

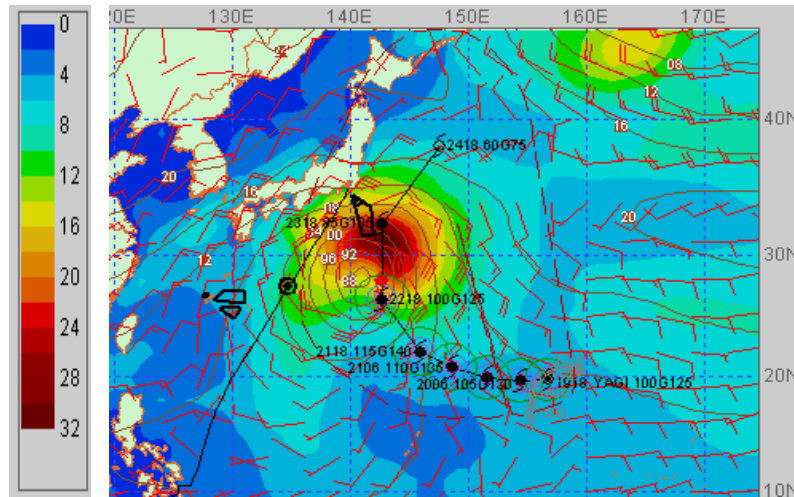
Detailed analysis of the Yagi sortie indicated that the JTWC/WW3 forecast delayed the onset of high seas near the Japanese coast, and if available at the time, could have provided an alternate scenario where the high seas did not impact the coast. However, it should be emphasized that the NOGAPS

---

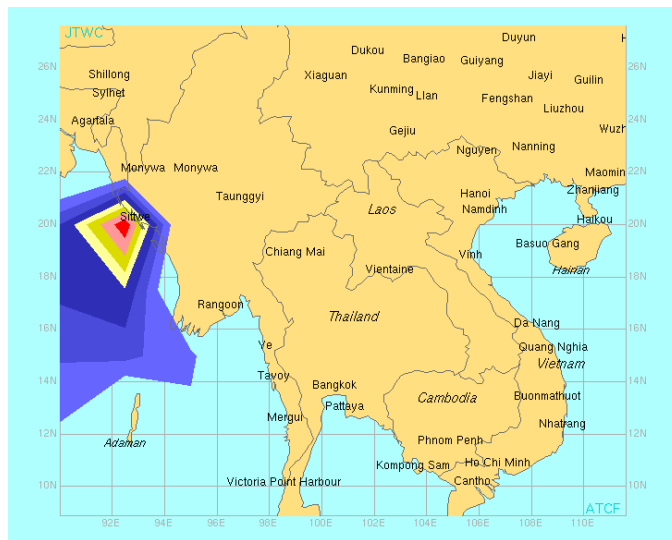
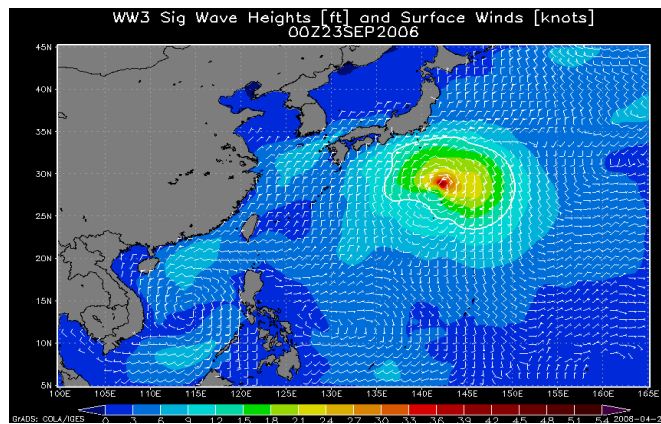
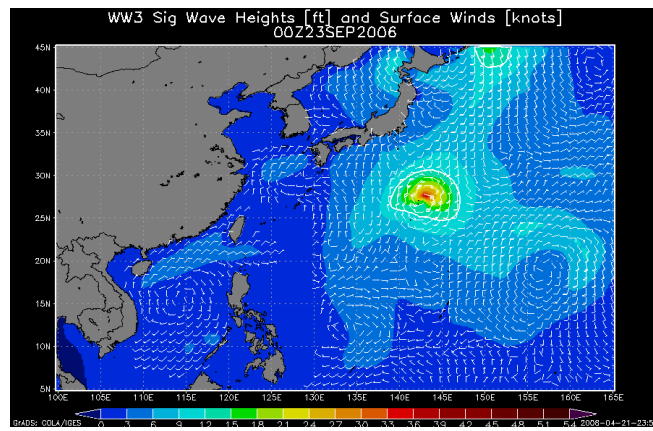
<sup>1</sup> NOGAPS is the Navy Operational Global Atmospheric Prediction System developed at NRL and run operationally at FNMOC.

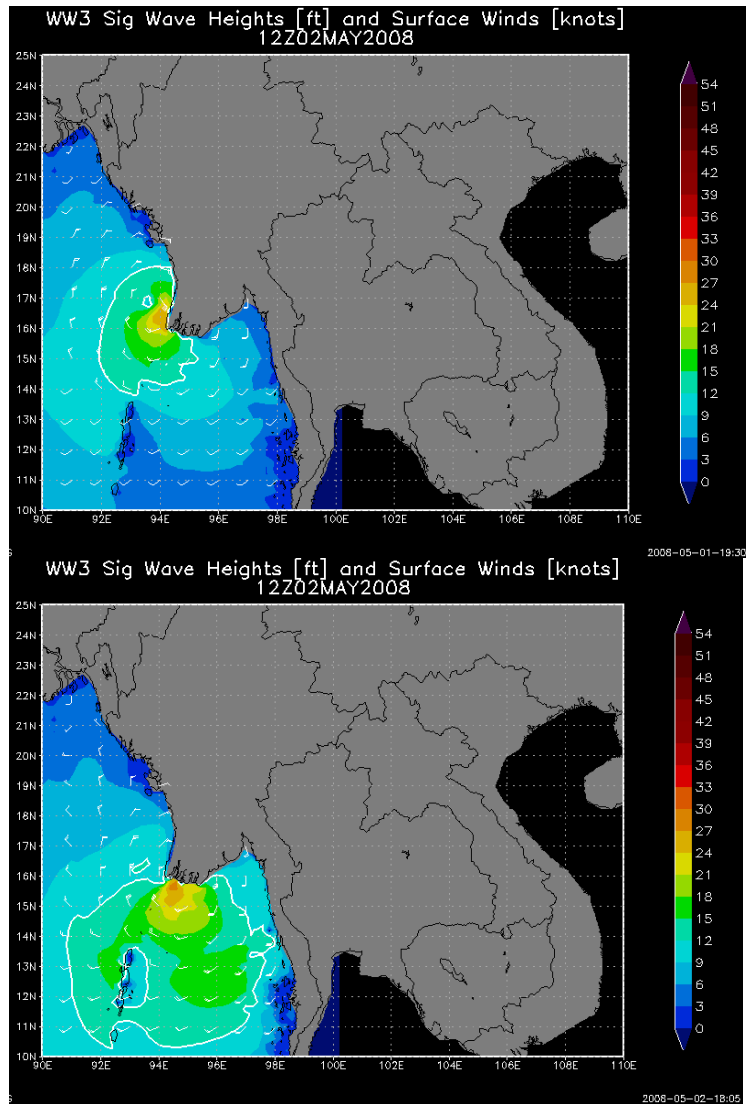
model track forecast in this case was approximately as skillful as the official forecast and that verification of forecasts between September 19 and September 23 (not depicted here) showed the algorithms to perform about the same. In summary, the authors believe that the JTWC/WW3 was probably right, but for the wrong reasons.

The same conclusion cannot be reached for Cyclone Nargis in the Northern Indian Ocean in 2008. Nargis has a two-day period when the NOGAPS and JTWC forecasts are quite different. For example, the April 29, 12 UTC 72-h forecast valid 12 UTC May 2, 2008 for each algorithm and a verifying analysis (hindcast) are shown in Figure 2. The NOGAPS/WW3 72-h forecast shows the high seas in the Northern Bay of Bengal while the JTWC/WW3 72-h forecast shows the high seas impacting Southern Myanmar. The JTWC/WW3 hindcast (Fig. 2 c) indicates that its typhoon position was far more accurate than NOGAPS/WW3.

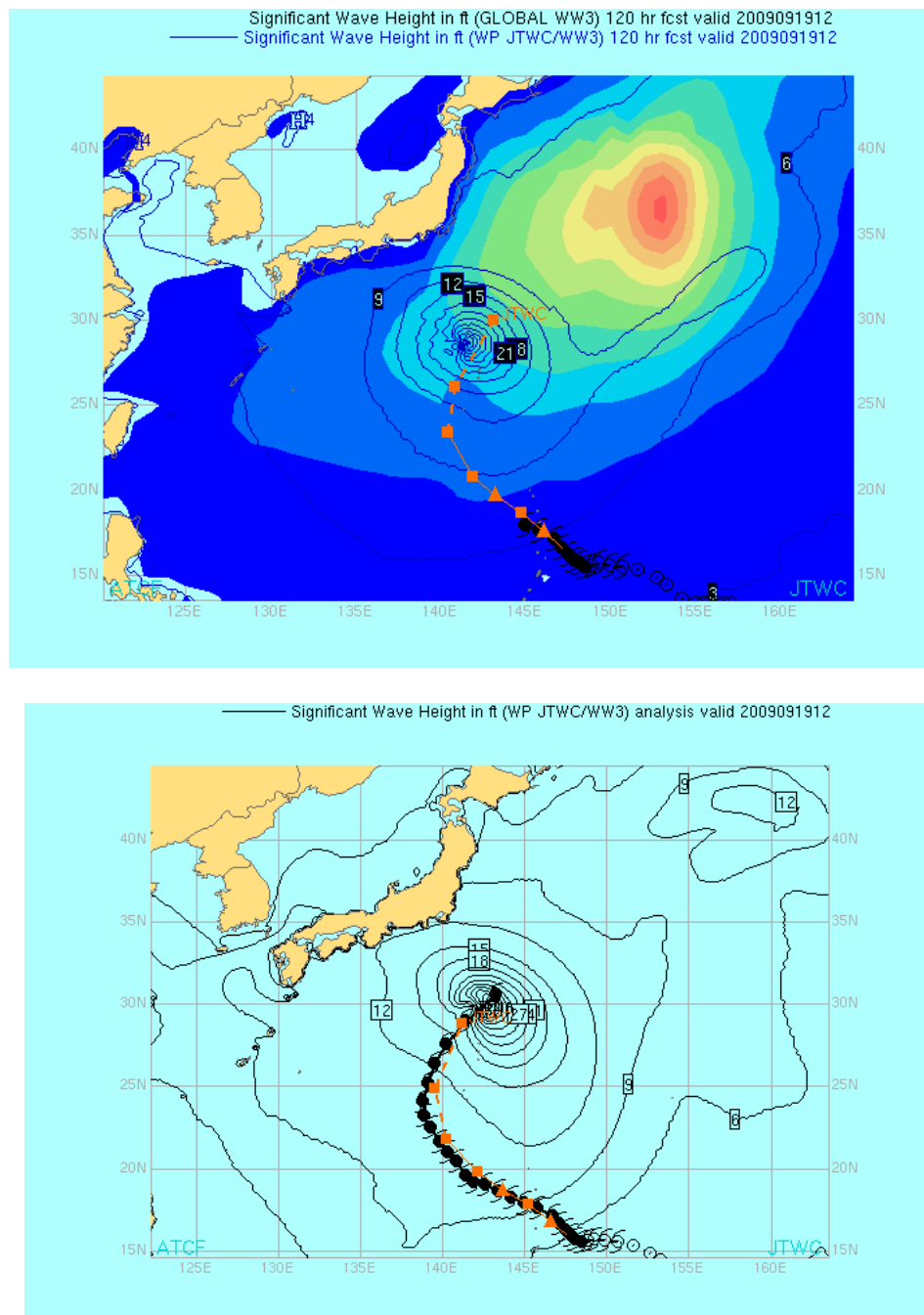


**Figure 1. (a) NOGAPS/WW384-h forecast (b) JTWC/WW3 84-h forecast and (c) JTWC/WW3 analysis of Yagi valid Sep 23 2006 00 UTC. 12-ft seas are light green shade and white contour outlines 12-ft seas in (b) and (c). Sortie route (black line headed SW), JTWC analyzed and forecast track are also shown on (a).**





**Figure 2. (a) NOGAPS/WW3 72-h forecast (b) JTWC/WW3 72-h forecast and (c) JTWC/WW3 verifying analysis (hindcast) of significant wave height for Nargis valid 12 UTC May 12008. 12-ft seas contour is shown as first blue shade in (a) and as white contour in (b) and (c).**



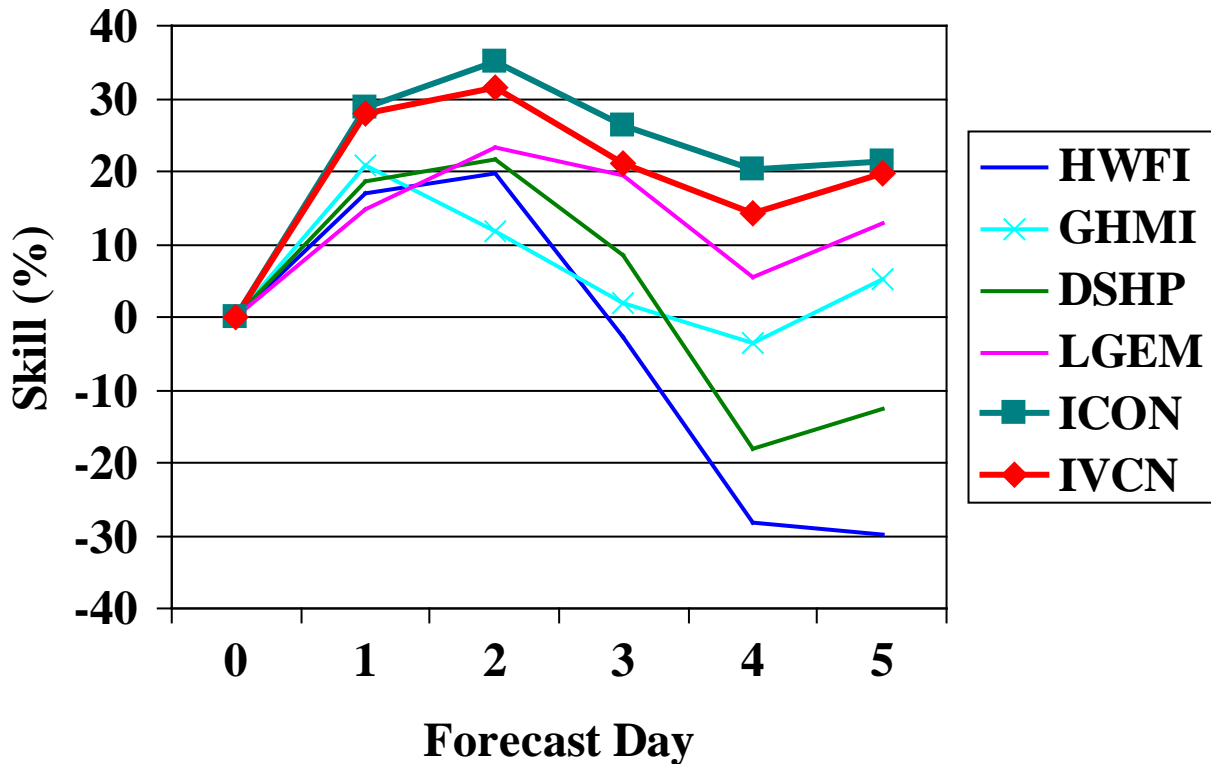
**Figure 3. (a) NOGAPS/WW3 (shaded) and JTWC/WW3 (contoured) 120-h forecasts for Choi-Wan and (b) JTWC/WW3 analysis verifying 12 UTC Sep 19, 2009.**

A similar scenario for Typhoon Choi-Wan during 2009 in the Western Pacific is shown in Figure 3. The NOGAPS tropical cyclone 120-h track forecast for Choi-Wan on September 15, 2009 was far northeast of the JTWC track forecast. As a result, the area of 12-ft seas was displaced northeast of the JTWC forecast (Fig. 3a). As in the case of Nargis, the JTWC/WW3 forecast is closer to the verifying analysis than the NOGAPS/WW3.

Finally, it should be noted that although the JTWC tropical cyclone track forecasts are generally slightly better than the NOGAPS forecasts, there will certainly be a large minority of cases in which the NOGAPS track forecasts are better than JTWC's. The JTWC/WW3 wave height field also tends to contain more extreme waves near the center of the storm and a smaller radius of 12-ft seas than NOGAPS/WW3. The authors attribute this to lower intensities and larger wind radii of the vortex as it is represented in the NOGAPS model.

## 2. Intensity forecast algorithm.

Last year we studied and implemented a consensus (average) of the most skillful models at the NHC. At the same time, the associated paper for this work was published in Weather and Forecasting. For the 2008 season, the intensity consensus at NHC outperformed all the member models and even the official forecast (Fig. 4).



**Figure 4.** Skill vs statistical baseline for four top-performing intensity aids (in the legend, HWFI=H-WRF, GHMI=GFDL, DSHP=SHIPS, LGEM=Logistic Regression Model) and two consensus aids (ICON=avg of intensity aid forecasts, IVCN=ICON aids +Navy GFDL model).



In 2008 we improved the western North Pacific basin consensus by including ocean heat content as a predictor in some of the consensus members. Results from tests on independent data indicated a modest 1-3% improvement in mean forecast error performance. The ocean heat content work was published in a journal and the aid was subsequently implemented at JTWC.

Three intensity forecast aids for the Southern Hemisphere have been developed, evaluated and published. The first (ST5D; Knaff and Sampson 2009a) is a statistical intensity forecast based only on best track information. This model serves as a skill baseline for other more complex models. The second forecast aid (STIPS; Knaff and Sampson 2009b) is a statistical-dynamical model, which uses best track information and NWP model data as input. In independent tests, this model demonstrates skill out to 48 h. The final forecast aid (ST11; Sampson and Knaff 2009c) is a consensus that includes STIPS ensemble members and GFDN. In evaluation with independent data, an ensemble of STIPS forecasts generally outperforms the individual members at 48 h. Addition of the GFDN member to the STIPS ensemble results in small but significant reductions in the mean forecast error at 24 and 48 h, but not at 72 h. Addition of more aids to the consensus yields mixed results.

## **IMPACT/APPLICATIONS**

The WAVEWATCH III work is intended to be a forecast aid for ship routing and shore sites with assets affected by high seas. The output is consistent with the operational tropical cyclone forecast, which can be much different than that of an individual NWP model. The concept has received interest and encouragement from Navy personnel and NOAA/NWS personnel. This season's forecasts, including currently active storms, can be found at

[http://www.nrlmry.navy.mil/atcf\\_web/wavewatch/page/web/tcww3.php](http://www.nrlmry.navy.mil/atcf_web/wavewatch/page/web/tcww3.php)

The intensity consensus aids produce deterministic forecasts that are intended for use at the Joint Typhoon Warning Center and the National Hurricane Center. Intended uses are for operational guidance and as baselines to evaluate the skill (in terms of mean forecast error) of other more complex ensemble techniques.

## **TRANSITIONS**

The WAVEWATCH III work transitioned to a 6.4 project managed by PMW-120: "Objective Probabilistic Aid for TC Sortie Decisions". The intensity consensus aids transitioned directly to the Joint Typhoon Warning Center and NOAA's National Hurricane Center through the ATCF. Both centers are using the aids in operations (as guidance) and as baselines for evaluating forecasts and other objective guidance.

## **REFERENCES**

- Tolman, H. L., B. Balasubramanian, L. D. Burroughs, D. V. Chalikov, Y. Y. Chao, H. S. Chen, and V. M. Gerald, 2002: Development and implementation of wind-generated ocean surface wave models at NCEP. *Wea. Forecasting*, 17, 311-333.
- Knaff, J. A., and C. R. Sampson, 2009a: Southern Hemisphere Tropical Cyclone Intensity Forecast Methods Used at the Joint Typhoon Warning Center, Part I: Control Forecasts Based on Climatology and Persistence. *Australian Meteorological and Oceanographic Journal*, 58, 1-7.

- Knaff, J. A., and C. R. Sampson, 2009b: Southern Hemisphere Tropical Cyclone Intensity Forecast Methods Used at the Joint Typhoon Warning Center, Part II: Statistical – Dynamical Forecasts, *Australian Meteorological and Oceanographic Journal*, 58, 9-18.
- Sampson, C. R., and J. A. Knaff, 2009c: Southern Hemisphere Tropical Cyclone Intensity Forecast Methods Used at the Joint Typhoon Warning Center, Part III: Consensus Forecast Experiments, *Australian Meteorological and Oceanographic Journal*, 58, 19-27.
- Sampson, C. R., J. L. Franklin, J. A. Knaff and M. DeMaria, 2008: Experiments with a Simple Tropical Cyclone Intensity Consensus. *Wea. Forecasting*, 23, 304-312.
- Sampson, C. R., and A. J. Schrader, 2000: The Automated Tropical Cyclone Forecasting System (Version 3.2). *Bull. Amer. Meteor. Soc.*, 81, 1231-1240.

## **PUBLICATIONS**

- Sampson, C. R., J. L. Franklin, J. A. Knaff and M. DeMaria, 2008: Experiments with a Simple Tropical Cyclone Intensity Consensus. *Wea. Forecasting*, 23, 304-312. [published, refereed]
- Knaff, J. A., and C. R. Sampson, 2009: Southern Hemisphere Tropical Cyclone Intensity Forecast Methods Used at the Joint Typhoon Warning Center, Part I: Control Forecasts Based on Climatology and Persistence. *Australian Meteorological and Oceanographic Journal*, 58, 1-7. [published, refereed]
- Knaff, J. A., and C. R. Sampson, 2009: Southern Hemisphere Tropical Cyclone Intensity Forecast Methods Used at the Joint Typhoon Warning Center, Part II: Statistical – Dynamical Forecasts, *Australian Meteorological and Oceanographic Journal*, 58, 9-18. [published, refereed]
- Sampson, C. R., and J. A. Knaff, 2009: Southern Hemisphere Tropical Cyclone Intensity Forecast Methods Used at the Joint Typhoon Warning Center, Part III: Consensus Forecast Experiments, *Australian Meteorological and Oceanographic Journal*, 58, 19-27. [published, refereed]
- Goni, G., DeMaria, M., Knaff, J., Sampson, C., Ginis, I., Bringas, F., Mavume, A., Lauer, C., Lin, I., Ali, M., Sandery, P., Ramos-Buarque, S., Kang, K., Mehra, A., Chassignet, E. and Halliwell, G. 2009: Applications of satellite-derived ocean measurements to tropical cyclone intensity forecasting, *GODAE Special Issue Feature, Oceanography*, 22, 176-183. [published, refereed]